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PHYSICOCHEMICAL PROCESSES IN TRANSPORTATION AND STORAGE OF GLASS BATCH

V. E. Manevich,[1] K. Yu. Subbotin,[1] V. D. Tokarev,[1] and R. V. Vakhitov[1]

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Conditions for hydration of soda and their effect on batch quality are considered. Regimes for transportation and storage of batch are determined. Recommendations for charging and discharging of batch are issued.

Clotting and stratification of glass batch may happen in the course of its transportation and storage. A result of this process is disruption of homogeneity of the batch, which has a negative effect on its quality, even when the mixer originally yields high-quality batch.

Let us analyze conditions that result in disruption of batch homogeneity.

Water is one of the batch components. Hydration of soda and sulfate take place in moistened batch and, accordingly, silica gels are formed [1 – 3]. The degree of water fixing in soda and sulfate hydrates can be different: $Na_2O \cdot H_2O$, $Na_2CO_3 \cdot 7H_2O$, and $Na_2CO_3 \cdot 10H_2O$. Furthermore, formation of metasilicic acid H_2SiO_3 and orthosilicic acid H_4SiO_4 and presence of free non-fixed H_2O are thermodynamically possible in certain conditions. High-water hydrates and sulfates intensely form at temperatures below 35°C. Since water is chemically fixed, the batch becomes excessively dry and prone to pulverizing and stratification.

At a temperature above 50°C the processes of formation of metasilica and orthosilica gels intensify. A prerequisite for this is a perceptible concentration of sand particles of colloid sizes (10^{-4} cm and less) in the glass batch reaching 10^9 particles per 1 cm^3 of batch.

Moistened batch is a disperse system, in which particles undergo in Brownian movement and, in collision under the effect of Van der Vaals forces, stick together and form coagulates.

Let us analyze the interaction between SiO_2 particle of colloid sizes, which results in bonded states.

The flux density of colloid-size particles is determined by the diffusion equation:

$$\frac{\partial n}{\partial t} = D\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial n}{\partial r}\right),$$

where n is the concentration of coagulation center; t is the time; D is the Brownian diffusion coefficient; r is the radial coordinate.

For boundary and initial conditions:

$$t = 0, \quad r > R, \quad n = n_0;$$
$$t > 0 \quad \begin{cases} r = R, & n = 0; \\ r \to \infty, & n = n_0. \end{cases}$$

The solution of the above equation has the following form:

$$n = n_0\left(1 - \frac{R}{r} + \frac{2R}{r\sqrt{\pi}}\int_0^{\frac{r-R}{2\sqrt{Dt}}} e^{-x^2}\,dx\right).$$

The flux of particles toward a sphere with radius R is

$$q = D\left(\frac{\partial n}{\partial r}\right)_{r=R} = Dn_0\left(\frac{1}{R} + \frac{1}{\sqrt{\pi Dt}}\right).$$

To estimate $\frac{r-R}{2\sqrt{Dt}}$, we will use the following data: the size of sand particles capable of forming a colloid 10^{-4} cm; a saturated solution of silicic acid contains approximately

[1] Institute of Glass Joint-Stock Company, Moscow, Russia; Stromizmeritel' Joint-Stock Company, Nizhny Novgorod, Russia; Salavatsteklo Joint-Stock Company, Ufa, Russia.

0.01% SiO_2, which, taking into account the collodization of the solution, additionally yields about 5×10^9 coagulation centers; the radius of the sphere in which Van der Vaals forces act (the coagulation sphere) is equal to twice the diameter of the particles: 2×10^{-4} cm.

The Brownian diffusion coefficient can be determined based on the Einstein formula [4]:

$$D \frac{kT}{3\pi\mu\rho} \approx 10^9 \text{ cm}^2/\text{sec},$$

where k is a constant; T is the absolute temperature; μ is viscosity; ρ is density.

It can be seen from these data that the increase in the number of coagulation centers is very high in the initial period and then becomes slower, i.e., initially non-bonded chemical water facilitates a stable state in the batch. Later, much depends on batch storage conditions (storage temperature and transportation conditions).

Let us consider two batch particles in a laminar flow. Let the coordinate x be directed along the axis of the bucket or the batch-storing hopper and Δy indicate the distance between the particles. According to M. Smolukhovskii [4], the following can be written:

$$v_x = k \frac{\partial v_x}{\partial y} \Delta y,$$

where v_x is the velocity in the direction of axis x.

The sand particles encounter each other at

$$\Delta y \le (R_1 + R_2) \sin\theta,$$

where θ is the angle between the axis x and the line connecting the centers of the particles.

The number of particles reaching the radius $2R$ is

$$N = n_0 v_x \cos\theta \times 4\pi(2R)^2 = 16\pi n_0 v_x R^2 \cos\theta.$$

Assuming the gradient $\frac{\partial v_x}{\partial y} = C \approx 10 \text{ sec}^{-1}$ to be constant, we obtain

$$\frac{\partial n}{\partial t} \times 16\pi n_0 CR^2 \Delta y \cos\theta = 32\pi n_0 CR^3 \cos\theta \sin\theta,$$

where $n = C_1 n_0 R^3 t$; $C_1 \approx 10^3$.

Thus, subject to a velocity gradient, the number of coagulation centers abruptly grows with time and, consequently, clotting of the batch is observed. Such conditions may arise in pouring batch from a height of more than 0.5 m, under intense vibration of the conveyor belt, in transportation in a truck, or in long-term storage.

It follows from an analysis of temperature, mechanical, and time conditions of batch storage that the batch should not experience vibration or other mechanical impacts, should be stored at a temperature of 35 – 40°C, and should not be stored more than 4 – 8 h.

The requirements imposed on temperature conditions of batch production, storage, and transportation are not always satisfied in practice in glass-making factories. Thus, after the Salavatsteklo Company installed highly efficient dosing and mixing equipment, the quality of batch estimated by means of analyzing samples discharged from the mixer improved perceptibly. Up to 95% batch samples had quality categories 1 and 2. After the batch was reloaded, discharged it from a height up to 12 m, and then transported on a belt located in an unheated gallery, the quality of the batch decreased to categories 4 – 5. After reloading of the batch with the height drop was eliminated and heating installed in the gallery, the quality of the batch in the charging pocket of the glass-melting furnace became identical to the batch quality registered immediately after mixing.

Let us analyze the conditions in which batch may stratify in charging and discharging of the hopper. Usually the level of material in the center of the hopper differs from the level near the walls; furthermore, when a batch is discharged, its components having different densities are unloaded at different rates. The mechanism of the hopper processes is analyzed in [5], where, however, consideration of random loading and unloading processes does not take into account the physical principles of the process; consequently, data obtained for ore cannot be extrapolated to the glass technology process.

Based on experimental data, we will assume that variation of the content of the main component in an initial material $X_k(t)$ is a random harmonic process,

$$\{X_k(t)\} = \{X_0 \sin[2\pi f_0 t + \theta(K)]\},$$

where X_0 and f_0 are constants; $\theta(K)$, i.e., the initial phase is a random value with a uniform distribution density $P(\theta)$ in interval $(0, 2\pi)$:

$$P(\theta) = \begin{cases} (2\pi)^{-1} & \text{for } 0 \le \theta \le 2\pi; \\ 0 & \text{for other } \theta; \end{cases}$$

$$X_k(t) = X \sin[2\pi f_0 t + \theta(K)] = X_1(\theta);$$

$$X_k(t+\tau) = X \sin[2\pi f_0 (t+\theta) + \theta(K)] = X_2(\theta);$$

$$R_x(t) \approx \frac{X_2}{2\pi} \times$$

$$\int_0^{2\pi} \sin(2\pi f_0 t + \theta) \sin(2\pi f_0 t + \theta) \sin[(2\pi f_0 (t+\tau) + \theta] d\theta =$$

$$\frac{X_2}{2} \cos(2\pi f_0^2).$$

In multi-flow loading and unloading of the batch-storing hopper (the general case), the auto-correlation function of the random process (the two-dimensional case) is

$$R_{X_1 + X_2}(t) = a_1 X_1(t) + a_2 X_2(t);$$

$$R_{X_1 + X_2}(t) = E[(a_1 X_1 K(t) + a_2 X_2 K(t)) \times (a_1 X_1 K(t+\tau) + a_2 X_2 K(t+\tau))] =$$
$$= a_1^2 R_{X_1}(\tau) + a_1 a_2 [R_{X_1 X_2}(\tau) + R_{X_2 X_1}(\tau) +$$
$$R_{X_2 X_1}(\tau)] + a_2^2 R_{X_2}(\tau)] = a_1^2 \frac{X_1^2}{2} \cos 2\pi f_0 \tau +$$
$$a_1 a_2 X_1 X_2 \cos 2\pi f_0 \tau + a_2^2 \frac{X_2^2}{2} \cos 2\pi f_0 \tau.$$

For $a_1 = a_2 = 0.5$

$$R_{X_1 + X_2}(0) = \frac{X_1^2}{8} + \frac{X_1 X_2}{4} + \frac{X_2^2}{8}.$$

At the moment $\tau = \tau_{st}$ the mutual correlation function $R_{X_1 + X_2, y}(\tau_{st})$ can be determined in the following way:

$$R_{X_1 + X_2, y}(\tau_{st}) = \frac{0.5(X_1 + X_2) y}{2}.$$

By introducing a harmonic transfer factor from the input signal to the output signal:

$$K = \frac{y}{0.5(X_1 + X_2)},$$

we obtain

$$R_{X_1 + X_2, y}(\tau_{st}) = K \frac{(X_1 + X_2)^2}{8} = K_1 R_{X_1 + X_2}(0).$$

Considering that the process is represented by a sum of harmonics:

$$R_{X_1 + X_2, y}(\tau_{st}) = \sum_{i=0}^{n} K_i (X_1 + X_2)^2,$$

it is possible to analyze the homogenizing capacity of the hopper based on one harmonic without sacrificing the validity of the conclusions. If two mixed batches that differ by 10% in their contents of the main component are loaded, the dispersion for $X_2 = 1.1 X_1$ is $DX_2 = R_{X_1 X_2}(0) = 0.605 X_1^2$, $D_{X_1 + X_2} = R_{X_1 + X_2}(0) = 0.551 X^2$, i.e., two-flow charging and discharging contribute to a better homogeneity of material.

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